

GLOBAL OPTICS CORRECTION IN RHIC BASED ON TURN-BY-TURN DATA FROM ARTUS TUNE METER*

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Abstract

Deviation of the optical functions from the model may result in reduced dynamic aperture, luminosity and beam polarization all of which are of particular interest in the polarized proton program at RHIC. Peak to peak beta beats as large as +/- 80% have been observed. In Run-13, we demonstrated that the optical functions can be corrected globally by two different approaches, either beta beat or phase error correction. The optics measurement, correction algorithm and beta beat and phase error measurements before and after correction will be presented.

INTRODUCTION

RHIC (Relativistic Heavy Ion Collider) has been running with large beta beat over the years for both heavy ion and polarized proton programs. The impact on dynamic aperture and beam polarization from optics error are expected, however hard to quantify. The optics errors manifest themselves as beta beats (relative error of beta functions), or as phase advance errors, and as the integral, the tune errors. Usually, the luminosity decreases because of enlarged β^* from the presence of beta beat. Therefore, luminosity is expected to benefit from optics correction even though many other parameters contribute as well. Model optical functions are usually used in correction in accelerators, like orbit, tune and chromaticity corrections [1] since calibration of optical functions is non-trivial. The errors in optics obviously set a limitation on the best performance of the corrections. In addition, many critical diagnostics rely on model optics as well. For instance, IPM (Ionization Profile Monitor) uses model beta functions to calculate the beam emittance. The accuracy of all these diagnostics are expected to be improved with the measurement of optical functions and correction. The above facts justify the need of a robust fast turn-around optics measurement and correction scheme.

OPTICS MEASUREMENT

In RHIC, two types of TbT (turn-by-turn) BPM data can be acquired for optics measurement. One is the betatron oscillation driven by the AC dipole [2]; the other is the free betatron oscillation initiated by the ARTUS kicker [3] (tune meter). The oscillation caused by the AC dipole is adiabatical and renders high signal to noise ratio. The ARTUS kicker affects only one bunch, so it is more robust in practice. All measurements and corrections in this paper are based on TbT BPM data acquired using the ARTUS kicker.

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TbT data analysis techniques, whether it is a time domain, frequency domain or any statistical method, should in principle deliver similar measurement resolutions provided they are employed to their best capacities. The author adopted a frequency domain method which produces ~0.2 deg phase measurement resolution [4] at RHIC.

In addition to measurements at BPM locations, beta functions at various critical devices can be interpolated based on the measured beta functions at nearby BPMs. First, one calculates the transfer matrices between the device and the upstream and downstream BPMs based on model optical functions. Then two equations can be established which relate the unknown beta and alpha at the device and the measured betas at the two BPMs.

$$\begin{cases} \beta_1 = R_{11}^2 \beta_0 - 2R_{11}R_{12}\alpha_0 + R_{12}^2 \frac{1+\alpha_0^2}{\beta_0} \\ \beta_2 = r_{11}^2 \beta_0 - 2r_{11}r_{12}\alpha_0 + r_{12}^2 \frac{1+\alpha_0^2}{\beta_0} \end{cases} \quad (1)$$

Here β_1, β_2 are the measured beta functions at BPM 1 and 2. R and r are the transfer matrices from the device to BPM 1 and 2 respectively. β_0 and α_0 are the unknown Twiss parameters at the device.

CORRECTION SCHEME

Global beta beat correction has been implemented on various accelerators successfully [5]. However, global phase error correction has been proposed but not demonstrated successfully [6]. The basics of the two corrections being applied in RHIC are similar. Suppose $(e_1, e_2, \dots, e_m)'$ is the optics error (beta beat or phase error) being measured, M is the response of optics errors to quadrupole strength variations in form of a matrix. The correction can be obtained by solving the following equations:

$$- \begin{pmatrix} e_1 \\ e_2 \\ \vdots \\ e_m \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} & \cdots & M_{1n} \\ M_{21} & M_{22} & \cdots & M_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ M_{m1} & M_{m2} & \cdots & M_{mn} \end{pmatrix} * \begin{pmatrix} k_1 \\ k_2 \\ \vdots \\ k_n \end{pmatrix} \quad (2)$$

The optics error on the left side are from both planes, on which proper weights can be applied based on the scale of the errors. The correction knobs in RHIC are the 72 quadrupoles with trim power supplies which all reside in the interaction regions [7].

The response matrix for beta beat correction can be calculated either by an optics program (MAD-X) simulation or analytically based on the online model (OptiCalc) optical functions. The analytical formula are presented

in Eq. 3. Betas in Eq. 3 are for the quadrupoles. The quadrupole integrated strength is assumed.

$$\begin{cases} M_{ij,x} = -\frac{\beta_{i,x}}{2 \sin \pi \mu_x} \cos(2\pi \mu_x - 2|\phi_{i,x} - \phi_{j,x}|) \\ M_{ij,y} = \frac{\beta_{i,y}}{2 \sin \pi \mu_y} \cos(2\pi \mu_y - 2|\phi_{i,y} - \phi_{j,y}|) \end{cases} \quad (3)$$

The results from both calculations were compared for RHIC at both the injection and store energies. Because of the fact that gamma-t quads are implemented in OptiCalc but not in the MAD-X model, the response matrices differ considerably from each other at injection energy. At full energy, the two results agree very well with each other since the contribution of gamma-t quads decreases with energy.

The response matrix for the phase error correction was only simulated with MAD-X. Therefore, the error in the phase response matrix is expected to be non-negligible due to the missing gamma-t quads at injection. At full energy, the impact of gamma-t quads on the phase response matrix should be minimal just like for the beta beat response matrix.

OPTICS CORRECTION

Due to time limitations and the known error in the model, a phase error correction was only attempted briefly at injection energy. With one iteration of corrections, the phase errors before and after correction at injection are shown in Figs. 1, 2, 3 and 4.

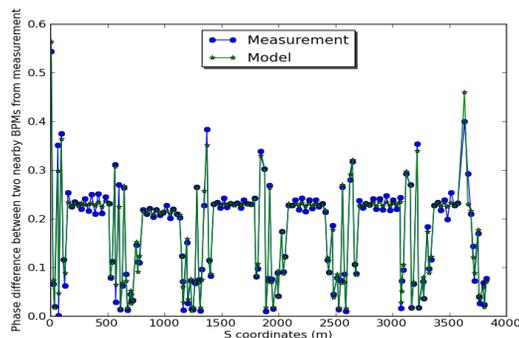


Figure 1: The measured and model phase advance in the horizontal plane before phase correction (in units of 2π).

The corresponding rms beta beat was reduced from 17.3% to 9.3% in the vertical plane, from 7.8% to 5.2% in the horizontal plane with the phase error correction.

Beta beat corrections were demonstrated in both rings at full energy. The beta beat before and after correction in the Blue ring are shown in Figs. 5 and 6. The applied integrated trim strengths for all 72 quads are shown in Fig. 7.

The phase measurement and correction has certain advantages over the beta beat correction. First, the phase measurement is model independent; secondly, the phase measurement is mostly immune to BPM calibration errors; and lastly, the phase correction will not introduce additional tune changes which have to be corrected. Phase error

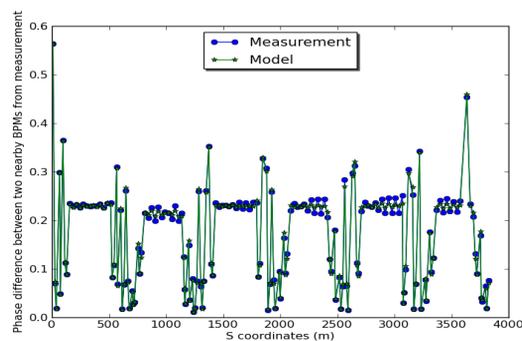


Figure 2: The measured and model phase advance in the horizontal plane after phase correction (in units of 2π).

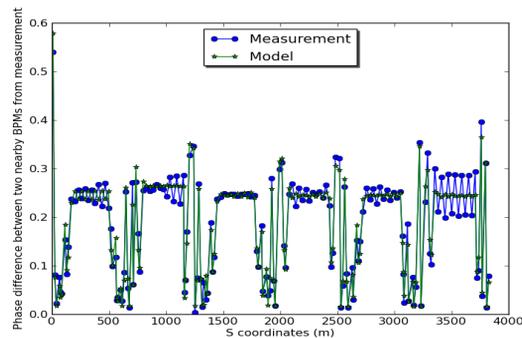


Figure 3: The measured and model phase advance in the vertical plane before phase correction (in units of 2π).

correction has been demonstrated successfully in RHIC at injection energy, however, not to its full capacity.

The beta functions at IPs (Interaction Points) are interpolated from the measurements before and after beta beat correction. The results are shown in Table 1 and 2. The numbers in parenthesis are the design values for the β^* .

SUMMARY

Both global optics correction schemes (beta beat and phase error correction) have been demonstrated successfully at RHIC based on ARTUS TbT BPM data. The beta

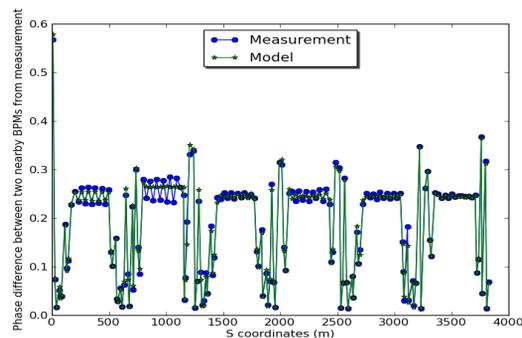


Figure 4: The measured and model phase advance in the vertical plane after phase correction (in units of 2π).

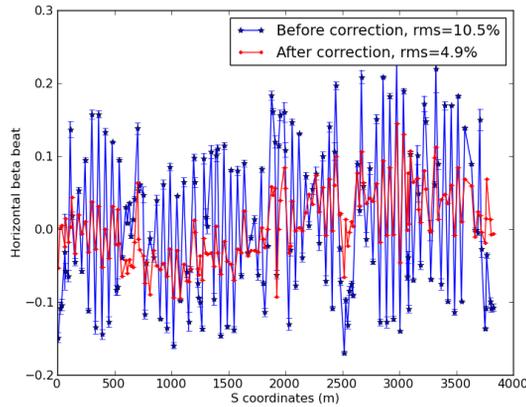


Figure 5: Beta beat in horizontal plane before (blue) and after correction (red).

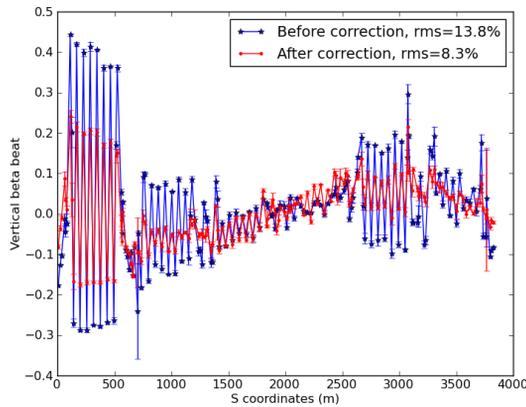


Figure 6: Beta beat in vertical plane before (blue) and after correction (red).

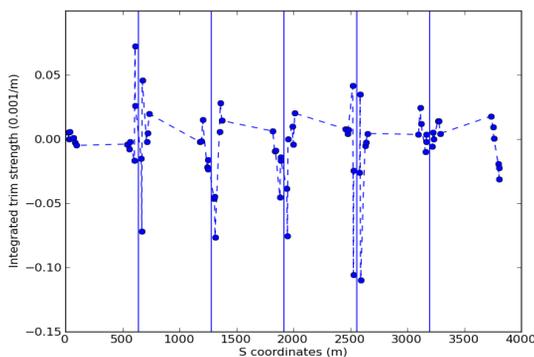


Figure 7: Applied integrated correction strength in the Blue ring at full energy.

Table 1: β^* at IPs in the Blue Ring Before and After Beta Beat Correction

	β_x (IP6)	β_x (IP8)	β_y (IP6)	β_y (IP8)
Before	0.74	0.63	0.82	0.73
After	0.66(0.64)	0.63(0.61)	0.69(0.63)	0.73(0.64)

Table 2: β^* at IPs in the Yellow Ring Before and After Beta Beat Correction

	β_x (IP6)	β_x (IP8)	β_y (IP6)	β_y (IP8)
Before	0.6	0.79	0.62	0.75
After	0.63(0.66)	0.66(0.6)	0.68(0.67)	0.70(0.68)

beat correction has since then been implemented operationally at store. The benefit on luminosity was observed [8]. The correction of β^* was verified by measurements after correction. Even though the phase response matrix has certain errors due to the missing gamma-t quads in the MAD-X model, phase error correction was demonstrated successfully at injection energy. Further studies are planned for the future. The result of a phase error correction is expected to be no worse than the beta beat correction.

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REFERENCES

- [1] M. Minty et al. Simultaneous orbit, tune, coupling and chromaticity feedback at RHIC. *Proc. of PAC11, New York, NY*, 2011.
- [2] M. Bai et al. Measuring beta function and phase advance in RHIC with an ac dipole. In *Proceedings of the PAC 2003.*, volume 4, pages 2204–2206. IEEE, 2003.
- [3] A.K. Drees et al. Artus: The tune measurement system at RHIC. In *AIP Conference Proceedings*, volume 546, page 341, 2000.
- [4] C. Liu et al. Precision tune, phase and beta function measurement by frequency analysis in RHIC. In *Proceedings of the IPAC 2013*.
- [5] R. Tomás et al. Record low β beating in the LHC. *Physical Review Special Topics-Accelerators and Beams*, 15(9):091001, 2012.
- [6] R. Calaga, R. Tomás, and F. Zimmermann. BPM calibration independent LHC optics correction. In *Particle Accelerator Conference, 2007. PAC. IEEE*, pages 3693–3695. IEEE, 2007.
- [7] H. Hahn. RHIC design manual, revision of october 2000. pages 2000–2003, 2000.
- [8] C. Liu et al. Implementation of optics correction on the ramp in RHIC. In *Proceedings of the NA-PAC 2013*.